Investigating of the thermal performance of utilised materials for an Integrated Collector Storage Solar Water Heater

[1]Mohammad Hassan Khanjanpour, [2]Rashid Panahi, [3]Akbar A. Javadi, [4]Mohammad Akrami, [5]Mohammad Rahnama, [6]Mehran Ameri.

[1,3,4] College of Engineering and Physical Sciences, University of Exeter

[2,5,6] Department of Mechanical Engineering, Shahid Bahonar University of Kerman, Kerman, Iran

[1]mk592@exeter.ac.uk, [2]panahi_rashid@yahoo.com, [3]a.a.javadi@exeter.ac.uk, [4]m.akrami@exeter.ac.uk, [5]mrah1338@gmail.com, [6]ameri_mm@uk.ac.ir

Abstract— Experiments are developed to investigate the performance of utilised materials for an environmental-friendly integrated collector storage (ICS) prototype as a solar water heater (SWH). The types of material of collectors have been investigated rigorously in order to obtain a real-dimensional curve of the deployed concentrator in the system. The parabola coordinates were found based on the observed variations of involute concentrator's angle (ψ) and Parabolic concentrator's angle (ω). The mean daily efficiency and the overnight thermal losses coefficient of mirror booster, steel sheet, and aluminum foil were calculated. The results are presented in the graphs.

Index terms: Concentrator; Integrated Collector Storage; Solar water heater; Thermal performance;.

I.INTRODUCTION

Industrialisation and the population increase cause a dramatic rise in the annual consumption of fossil fuel [1]. Solar energy is one of the reliable candidate sources which can provide 173,000 million miles amount of energy daily to the earth [2].

In ICS types of passive SWHs, the storage tank and the collector are not separated from each other. The cold water is directly connected to the collector and heated by the sun. Unlike other systems, hot water remains in the collector until it is consumed and then directly used by the collector. ICS systems require larger storage sources (to increase absorption capacity) than conventional systems, which also protects the system against frost [3].

II.GEOMETRIC DESIGN OF THE ICS SWH SYSTEM

The storage tank is the central part of an ICS SWH. Its function is to absorb solar radiation and transfer thermal energy to the stored water. The size and shape of a storage tank have an important effect on the absorption of solar energy in such systems. The more area of the storage tank is under the sun's exposure, the less time takes for warming water. However, in a normal environment, a high-surface storage tank will lose a significant part of the energy through heat transferring and radiation with long wavelengths, and mostly during the night due to heat loss with the sky [4]. According to studies carried out by Keshavarzia and et al. [5], water consumption in rural regions of Iran is about 120 L/d per person. In order to fulfill this amount of household's demand of water, the diameter of the storage tank was chosen 30 cm and the length of the storage tank selected 200 cm, which in case the volume of storage tank became 140 L. The material of the storage tank should be selected with high conductivity coefficients such as aluminum, copper and galvanised iron/steel [6]. According to the economic considerations, the galvanised sheet was selected for this specific study. The thickness of the sheet should be chosen in order to withstand the pressure of the water, in addition to

having the lowest thermal resistance against the heat transfer [4]. In the opinion of the available sheets in the market, the thickness of 1 mm was chosen.

III. Geometry of CPC concentrator

According to Tripanagnostopoulos's studies [7], the symmetric CPC concentrator was selected to achieve the highest efficiency (See Figure 1).

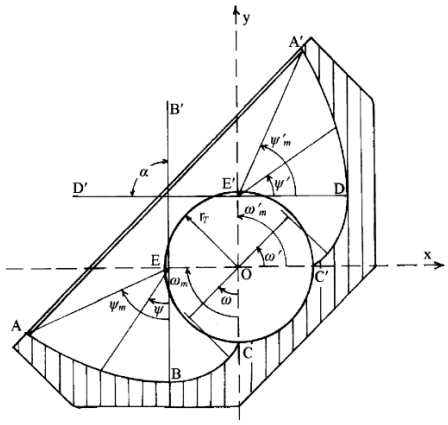

Figure 1 - Cross-section view of a symmetric CPC [7]

Table 1 - General characteristics of the water heater

Complete system	Dimension	200×64×113 cm
	Aperture area of systems	1.89 m^2
	Material of aperture	Simple flute glass
Concentrator	Kind of concentrator	CPC
	Material of concentrator	Steel sheet, aluminum foil, and mirror booster
Storage tank	Capacity	140 liters
	Material	Galvanised sheet
	Covering material	Black enamel

IV. Construction and assembly

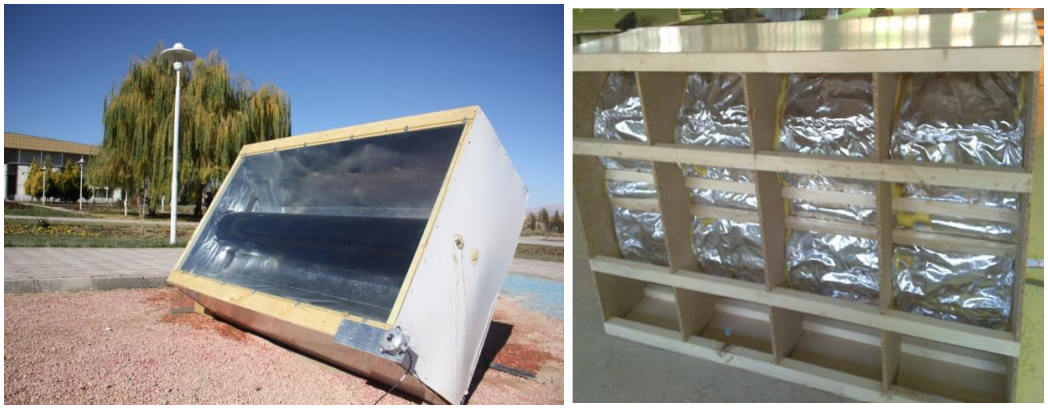

Figure 2: The constructed ICS SWH

In order to achieve optimal performance, selecting a proper concentrator has an important effect on the thermal efficiency of a solar system [8]. In this work, it was aimed to experiment with the installation of various concentrators on the system and the evaluation of their thermal performance. According to available material for concentrators in the market, Steel sheet and Aluminum foil were selected, while a mirror reflector is added to boost the energy inside the system (See Table 1).

The first experiment was performed by installing the aluminum foil on the system and tested for three consecutive days. On the first day of the test, the temperature of the water of inside the storage tank reached 43 °C, on the second day 53 °C and on the third day 61 °C, when the water temperature at the start of all tests was 21 °C. Replacing the concentrator and installing the steel sheet and the mirror, the temperature of the water inside the storage tank increased throughout the day (See Figure 2).

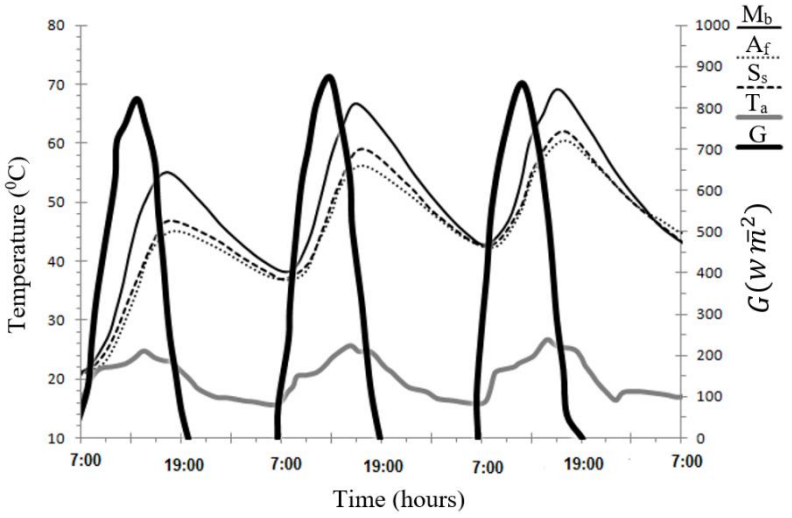

Figure 3 - Temperature changes for three consecutive days

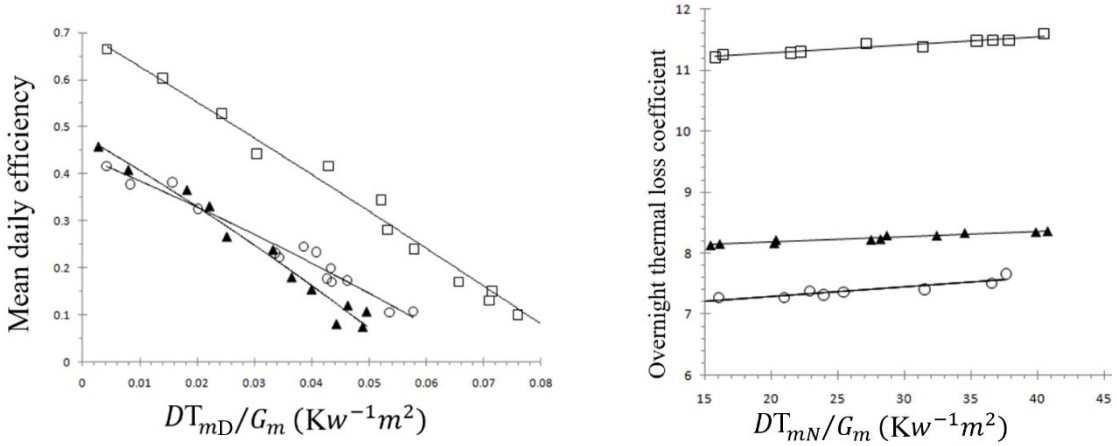

Figure 4 – Overnight thermal losses coefficient and Mean daily efficiency (M_b: □, A_f: ○, S_s: ▲)

It can be found from the Figure 3 that the temperature reduction during the night for the mirror, steel sheet, and aluminum foil is respectively the highest. Using the graphs of temperature

variation and according to the daily efficiency equations and thermal loss coefficient, the graphs of them are plotted in Figure 4. By fitting a second-order polynomial to the points obtained, the mean daily efficiency equation is obtained, and for each material presented in Table 2. According to equations in Table 2, the highest coefficient C of mean daily efficiency equations is 0.667 for the mirror, the steel sheet is 0.476 and the aluminum foil is 0.4372, which indicates that the mirror output is better than the steel sheet and aluminum foil during the day.

Table 2. Equations of mean daily efficiency of concentrators

Material	mean daily efficiency η_d
Mirror booster	$\eta_d = 0.667 - 7.4215(DT_{mD}/G_m) - 4.418(DT_{mD}/G_m)^2$
Steel sheet	$\eta_d = 0.5262 - 8.2903(DT_{mD}/G_m) - 11.561(DT_{mD}/G_m)^2$
Aluminum foil	$\eta_d = 0.4872 - 5.128\ (DT_{mD}/G_m) - 14.072(DT_{mD}/G_m)^2$

In the same way, a first-order line for the obtained points of the thermal loss coefficient is fitted, and its equation for each concentrator is shown in Table 3. According to the thermal losses coefficient, the main part of equation for the aluminum foil is 6.9877, for the steel sheet is 8.0035 and for the mirror is 11.016. It can be concluded that the thermal protection of the aluminum foil is better than steel sheet and mirror booster.

According to obtained results, although the steel sheet was the second efficiency among experimented materials, it has acceptable heat loss in compression mirror. I addition, it is cheaper and easy to install [9]. Therefore, the steel sheet was selected in the ICS SWH system for monthly experiments (See Figure 4).

Table 3. Equations of Overnight thermal loss coefficient U_s for different concentrators

Mirror booster	$U_s = 11.016 + 0.0132(DT_{mN}/G_m)$
Steel sheet	$U_s = 8.0035 + 0.009(DT_{mN}/G_m)$
Aluminum foil	$U_s = 6.9877 + 0.0153(DT_{mN}/G_m)$

Conclusion

The presented ICS SWH can be utilised to heat the water in houses or preheat water in small to medium-sized industries. The main advantage of this system comparing to the available models in the market are inexpensive materials, monolith, portability, easy installation and operation, and long maintenance period provide an alternative solution for heating water, especially in the remote rural areas.

Experimenting the three common concentrators, mirror booster, steel sheet, and aluminum foil, it was shown that using mirror can increase the thermal efficiency of the system, but on the other hand, more thermal loss the system was also measured. Steel sheet is the optimal solution as of its economically affordable, non-breakable and also easy to install in rural areas.

References

1. Quaschning, V.V., *Renewable Energy and Climate Change, 2nd Edition*. 2019: Wiley.
2. Garcia, A.G., N. Sras, and M. Zuhir, *Energy Resources Analysis.* 2017.
3. Jamar, A., et al., *A review of water heating system for solar energy*

applications. International Communications in Heat and Mass Transfer, 2016. **76**: p. 178-187.
4. Smyth, M., P. Eames, and B. Norton, *Integrated collector storage solar water heaters.* Renewable and Sustainable Energy Reviews, 2006. **10**(6): p. 503-538.
5. Keshavarzi, A., et al., *Rural domestic water consumption behavior: A case study in Ramjerd area, Fars province, IR Iran.* Water research, 2006. **40**(6): p. 1173-1178.
6. Kenisarin, M. and K. Mahkamov, *Solar energy storage using phase change materials.* Renewable and sustainable energy reviews, 2007. **11**(9): p. 1913-1965.
7. Tripanagnostopoulos, Y. and M. Souliotis, *Integrated collector storage solar systems with asymmetric CPC reflectors.* Renewable Energy, 2004. **29**(2): p. 223-248.
8. Harris, J.A. and T.G. Lenz, *Thermal performance of solar concentrator/cavity receiver systems.* Solar energy, 1985. **34**(2): p. 135-142.
9. Smyth, M., P. Eames, and B. Norton, *Techno-economic appraisal of an integrated collector/storage solar water heater.* Renewable Energy, 2004. **29**(9): p. 1503-1514.